

Predicting scenic beauty of forest stands in Catalonia (North-east Spain)

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Abstract: Relative preferences of 90 images of forest stands, photos and virtual reality images were investigated by the internet to develop a quantitative model for estimating scenic beauty preferences at the stand level. The relative priority values obtained from the questionnaire of a total of 259 judges were analyzed using regression methods for pairwise comparisons. Two models were developed based on two different groups of stands. Both models indicate that the priority of a forest stand increases with an augment in the number of bushes and trees, and also with the mean diameter of trees. On the other hand, the priority is low with large number of pines and small trees. Stands represented by photos receive better priority values than those represented by virtual reality images. When the background of the judges (gender, country or occupation) was included into the model as additional predictors, no significant improvements are achieved.

Keywords: analytic hierarchy process; landscape preferences; pairwise comparison; virtual reality

Introduction

Forest supplies, in addition to wood, a diversity of important non-wood products, and plays an important role in soil protection, regulation of water resources, fixation of CO₂, biodiversity conservation, and in providing recreation activities (Palahí et al. 2004). Despite this, forest planning has dealt almost exclusively with timber production, trying to maximize the economic profit for the forest owner. However, the current demand of the society is to include non-timber forest services into forest planning. The single-purpose timber production of the past decades is being redirected towards ecological conservation and multiple-use of forests.

The purpose of forest planning is to support forestry deci-

sion-making by suggesting management alternatives, providing information about their consequences, and helping the decision maker to rank the alternatives. In multi-objective forest planning, different objectives and forest management practices are evaluated in order to achieve the highest satisfaction value for the decision makers. Multi-criteria decision analysis is an important tool when a decision has to be taken from multiple objectives. In order to optimize management, numerical values of all decision criteria are required, i.e., products and services that are of interest. However, in certain cases, the numerical values are not easy to obtain because the value itself arises from a subjective perception. One particular case is the amenity of a forest stand. Especially in public forest and in areas used for recreation it is important to know how different forest management options affect people's perceptions about the scenic beauty of the stand (Silvennoinen et al. 2002).

Integration of scenic beauty into the decision-making process of multiple-use forestry requires a relation between scenic beauty perception and other physical forest features that are managed to meet broader goals (Brown and Daniel 1986). Earlier studies have shown reasonable success in relating scenic beauty to forest characteristics (Arthur 1977; Savolainen and Kellomäki 1981; Schroeder and Daniel 1981; Pukkala et al. 1988; Rudis et al. 1988; Silvennoinen et al. 2002).

Nowadays several methods can be used to collect and analyze people's preferences concerning environmental issues. These methods have been adapted from psychophysics, a branch of psychology established in the early 1800s (Hull et al. 1984). These procedures provide precise quantitative indices based on people's perceptions of stimuli. Each of these methods requires information from a survey or experimental situation. A common

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way to design the survey is through the use of photographic images (Brown and Daniel 1986; Rudis et al. 1988; Daniel et al. 1989; Silvennoinen et al. 2001; Silvennoinen et al. 2002). One of the most used methods is the Scenic Beauty Estimation (SBE) developed by Daniel and Boster (1976). Here, participants rate their preference for different photographic slides of landscapes on a 1–10 scale. Then, researchers try to relate the ratings to the physical features of the forest like number of trees, average tree diameter, etc. (Daniel and Boster 1976; Brown and Daniel 1984, 1986; Hull and Buhoff 1986; Hull et al. 1984; Ribe 1990). Another relevant group of studies is based on the Analytic Hierarchy Process (AHP) method, introduced by Saaty (1977). These studies analyse the relative preference of pairs of images and also try to relate the preferences to physical characteristics (Silvennoinen et al. 2001).

Photographs have been found to be acceptable surrogates of real vistas for the study of visual quality (Bergen et al. 1995, Shafer and Richards 1974; Zube et al. 1974, 1975; Daniel and Boster 1976; Shuttleworth 1980). However, the use of photographs can present some limitations. To find a set of photographs of forest stands representing a wide range of forest structures and species, compositions may require an extensive search of locations. Additionally, non-existing stand types, but reachable through forest management, can not be included in the study. Computer-generated images that portray the spatial and temporal impact of forest operations, such as virtual reality models, can solve some of the limitations arising from the use of photographs.

The aim of this study is to develop a model that predicts the scenic beauty of a forest stand, depending on variables related to forest structure and management. The model is based on the relative preferences of a group of persons who evaluated pairs of stands. Regression methods for pairwise comparisons (Alho et al. 2001), internet surveys, real images and virtual reality images were used in the study. Gonzalez et al. (2007) used similar data gathering and analysis methods to model the perception of experts on forest fires with respect to the vulnerability of forest

stands to fire. The results were encouraging. Due to the fact that scenic beauty preferences are personal, a slightly different approach was required. A large number of ordinary people were employed as judges instead of a small number of experts, allowing the analysis of differences between groups of judges depending on their gender, nationality, occupation, and level of education.

Materials and methods

The present study used a similar data gathering process and analysis methodology as González et al. (2007). The following steps were followed to estimate the scenic beauty of forest stands:

- 1) Create a set of images, representing different forest stands
- 2) Create an internet questionnaire for the comparison of pairs of images
- 3) Recruit evaluators to fill in the internet questionnaire
- 4) Compute the priority value of each stand in terms of scenic beauty and develop a model for the relationship between stand characteristics and scenic beauty

Data gathering

An internet questionnaire was created to collect preference data. The questionnaire was designed in a way that images representing forest stands has to be compared pairwise. Each slide of the questionnaire includes a pair of images and a symmetric scale with nine verbal values of comparison. Using this scale, evaluators have to decide whether one of the two stands is more beautiful (Saaty 1977). The judge recorded the opinion on a form by selecting one of the following alternatives: absolutely superior, extremely superior, very much superior, superior, and equal (Fig. 1). Each of the verbal evaluations corresponded to a numerical value which was afterwards used in the statistical analysis.

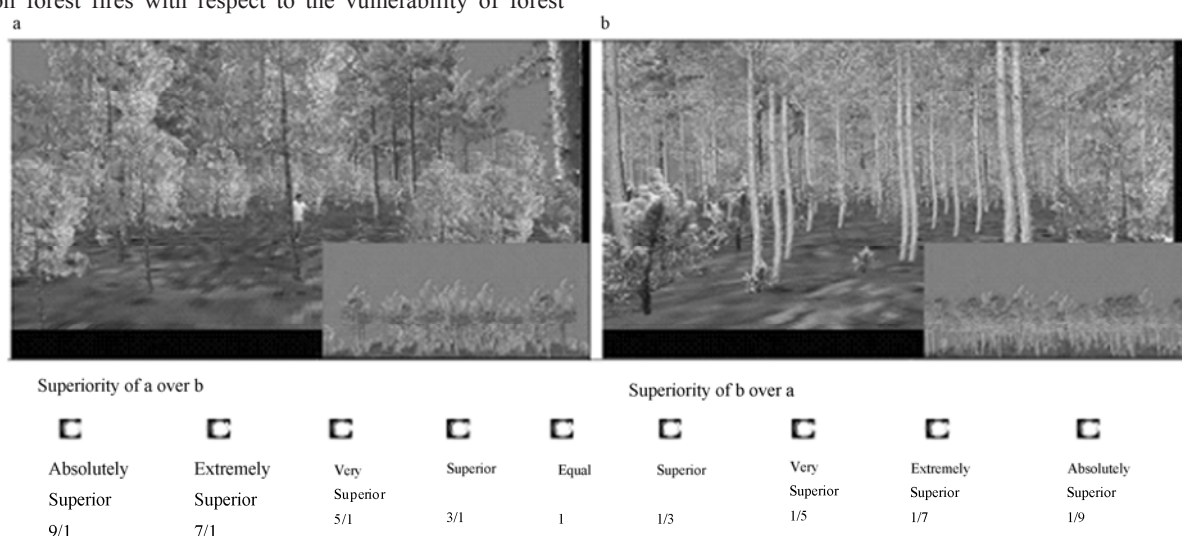


Fig. 1 An example of the pairwise comparisons used in the questionnaire with the numerical values corresponding to each verbal expression.

The numerical scale represents the priority of (a) over (b)

The images compared in the questionnaire represent a wide range of forest stands in Catalonia. The total set of images comprised 90 images, of which 73 images are screenshots of 3D virtual representations of forest stands (the later referred to as virtual reality images, VRI) and 17 images are photographs of existing stands. Photographs were included to detect possible differences in the perception of photos and VRIs. Each stand represented by a photograph also has a VRI. Virtual reality images were created using the program Monte (Pukkala 2002). For every image all the common stand characteristics (mean diameter,

number of trees per hectare, etc.) were known. The stands were divided into two groups in order to see the sensitivity of modelling results to modelling data (Table 1). Group A consisted of 49 images (10 of them were photos), and group B consisted of 41 images (7 photos). Before creating the questionnaire, the images were randomized to prevent order effects; afterwards a label was assigned to each image (1, 2, 3, ..., n). The pairs of images were formed thus image 1 was compared to 2, 2 to 3, ... and n-1 to n. A total of 88 pairs ((nA-1)+(nB-1)=88) were obtained, 48 pairs in group A and 40 pairs in group B.

Table 1. Means and ranges of the stand characteristics in group A and group B. Group A consists of 49 images (10 of them were photos), and group B consists of 41 images (7 photos).

Characters	Group A			Group B		
	Min.	Average	Max.	Min.	Average	Max.
Number of bushes	0	469	2450	0	376	1750
Number of trees	0	665	2356	0	772	3037
Number of trees dbh<5cm	0	396	2500	0	436	4000
Number of pines dbh>5cm	0	549	2356	0	720	3037
Basal area (m ² /ha)	0	28.82	128.20	0	31.13	128.20
Relative standard deviation of the diameters (sd/dm)	0	0.36	1.22	0	0.34	1.00
Basal-area-weighted mean diameter of trees (cm)	0	27.91	47.80	0	26.80	40.90

The questionnaire was presented at different Spanish and Finnish universities, and on an international web page of foresters. A total of 276 answers were received, but only 259 were completed in a correct way and therefore included in the study. Before submitting the information the judges were asked to give some personal data: gender, education, country and whether his/her work is related to environmental sciences or forestry (Table 2).

Table 2. Background of the evaluators

Personal data	Value	Number	Percentage(%)
Gender	Male	117	45
	Female	127	49
	Unknown	15	6
Work related with forest science	Related	122	47
	No related	137	53
Education level	Master degree	117	45
	Bachelor degree	80	31
	College education	48	19
	Elementary school	3	1
	Unknown	11	4
Country	Spain	137	53
	Finland	49	19
	Others	73	28

Statistical analysis

The study used regression methods for pairwise comparisons, developed by Alho et al. (2001). The calculation procedure of the Analytic Hierachy Proccess (AHP) (Saaty 1977) was used to convert the verbal assessments into numerical priorities measured on the ratio scale. The ratio scale was derived using an ei-

genvalue calculation on a matrix formed from the quantified comparisons. Then these priorities were regressed against stand characteristics using the above method. The original method of AHP (Saaty 1977) needs a complete set of paired comparisons of forest stands, thus the number of comparisons tends to be extremely high. The regression method used in this study (Alho et al. 2001) solved this problem. The regression approach permits the estimation of the priorities from much fewer comparisons. Moreover, the usual problem of missing data is removed.

Let $r(i, j, k)$ be the evaluation of judge k for his relative preference of image i over image j . The response in the regression analysis is $y(i, j, k) = \log(r(i, j, k))$. If we suppose that for each stand i there are p explanatory variables $x_{i1}, x_{i2}, \dots, x_{ip}$ and the value of priority v of stand i is of the following log-linear form (Alho et al. 2001, see Eq. 4)

$$v_i = \exp(\mu + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_p x_{ip}) \quad (1)$$

where μ is the intercept and $\beta_i, i = 1, 2, \dots, p$ are the regression coefficients, then the regression model can be formulated as follows:

$$y(i, j, k) = (\mu + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_p x_{ip}) - (\mu + \beta_1 x_{j1} + \beta_2 x_{j2} + \dots + \beta_p x_{jp}) + \varepsilon(i, j, k) \\ \beta_1(x_{i1} - x_{j1}) + \beta_2(x_{i2} - x_{j2}) + \dots + \beta_p(x_{ip} - x_{jp}) + \varepsilon(i, j, k) \quad (2)$$

Where, $\varepsilon(i, j, k)$ is the error term with expectation zero, and term μ cancelling out.

Using this methodology, scenic beauty preference models

were fitted for both groups of images. As this methodology also allows the computation of the internal consistency of the judges, and some inconsistencies can be expected in human evaluation processes, an analysis of inconsistency of evaluations was done. A consistency threshold (R^2) for each judge was subjectively established at 0.25. Judges with R^2 lower than 0.25 in any of the evaluations (Group A or Group B) were removed. New models were developed with the remaining judges. Additionally, models were fitted for the different judge sub-populations according to gender, nationality, relation of judge's work to forestry, and level of education. The predictors had to fulfil two criteria to be included in the models: be significant at the 0.05 level and have the same sign of the regression coefficients in the models for both groups.

Results

After analyzing several variables representing stand characteristics, the models developed for predicting the preference with respect to the stands' scenic beauty has the following form:

$$\ln(v) = \beta_1 NB + \beta_2 NT + \beta_3 Dg + \beta_4 NP > 5 + \beta_5 DV + \beta_6 NT < 5 \quad (3)$$

Where, v is the priority of stand with respect to scenic beauty, β_i ($i = 1, 2, 3, \dots, p$) the regression coefficient, NB the number of bushes per hectare; NT the number of trees per hectare; $NP > 5$ the number of pines per hectare with diameter at breast height more than 5 cm; $NT < 5$ the number of trees per hectare with diameter at breast height less than 5 cm; Dg the basal-area-weighted mean diameter (cm) of trees; DV a dummy variable that indicates whether the stand is represented by virtual reality image (0) or by photograph (1).

According to the models (Table 3), the high densities of trees or bushes increase the scenic beauty. Also, the larger the diameter, the higher the scenic beauty is. Large numbers of small trees and pines reduce the scenic beauty. Additionally, significant differences are observed between VRIs and photographs. The photographs obtain higher scores than VRIs of the same stands.

Table 3. General and group-specific models for scenic beauty (beta coefficients) and their R^2 based on the analysis of images in groups A and B. Group A consisted of 49 images (10 photos), and group B consisted of 41 images (7 photos).

Predictor		<i>NB</i>	<i>NT</i>	<i>Dg</i>	<i>NP>5</i>	<i>DV</i>	<i>NT<5</i>	R^2
Group A	All judges	259	0.0001378	0.0006723	0.02236	-0.000619	0.4909	0.152
	Consistent	207	0.0001564	0.0007102	0.02351	-0.0006423	0.5844	0.183
	Sex	Men	0.0001557	0.0006408	0.02342	-0.0005518	0.466	0.155
		Women	0.0001953	0.0007115	0.02189	-0.0006944	0.4888	0.1487
	Country	Spain	0.0001619	0.0007683	0.0229	-0.0007759	0.3305	0.1377
		Finland	0.0002279	0.000794	0.01883	-0.0009204	0.4417	0.1488
		Other	0.0001628	0.0005259	0.01968	-0.0004681	0.609	0.1601
	Work related to forestry	Yes	0.00018807	0.0006257	0.02394	-0.0005729	0.4918	0.1729
		No	0.00009235	0.0007142	0.02093	-0.0006605	0.4901	0.1357
Group B	All judges	259	0.0001031	0.0005563	0.02237	-0.0003081	0.3467	0.2561
	Consistent	207	0.00009921	0.0005628	0.02362	-0.0002886	0.4401	0.296
	Sex	Men	0.0001271	0.0004816	0.02294	-0.0002581	0.3558	0.2592
		Women	0.00008708	0.0006566	0.02246	-0.000387	0.327438	0.256
	Country	Spain	0.00009428	0.0006524	0.02224	-0.000402	0.296	0.2552
		Finland	0.00016	0.0002761	0.0203	-0.00007115	0.415	0.25
		Other	0.00004394	0.0007021	0.0257783	-0.0003967	0.385778	0.2835
	Work related to forestry	Yes	0.000136	0.0004498	0.0245	-0.0002144	0.3046	0.2634
		No	0.00007317	0.000652	0.02044	-0.0003925	0.3848	0.2522

Note: *NB* the number of bushes per hectare; *NT* the number of trees per hectare; *NP>5* the number of pines per hectare with diameter at breast height more than 5 cm; *NT<5* the number of trees per hectare with diameter at breast height less than 5 cm; *Dg* the basal-area-weighted mean diameter (cm) of trees; *DV* a dummy variable that indicates whether the stand is represented by virtual reality image (0) or by photograph (1)

The average internal consistency of the judges is 0.39 for images of group A, and 0.47 for images of group B. After analyzing the individual consistency of each judge, only 52 judges in total 259 judges showed the consistency level lower than 0.25 in one of the comparisons, and the remaining 207 judges has an average consistency of 0.44 in group A and 0.50 in group B. After removing the evaluations of the inconsistent judges and developing new models with the consistent ones, it is observed that the re-

gressions coefficients does not change much but the models' degree of explained variance increased (Table 3). The predictive capacity of the models developed by using the consistent judges is easily stated when the observed priorities of the images in each group are plotted against the priorities predicted using the models (Fig. 2).

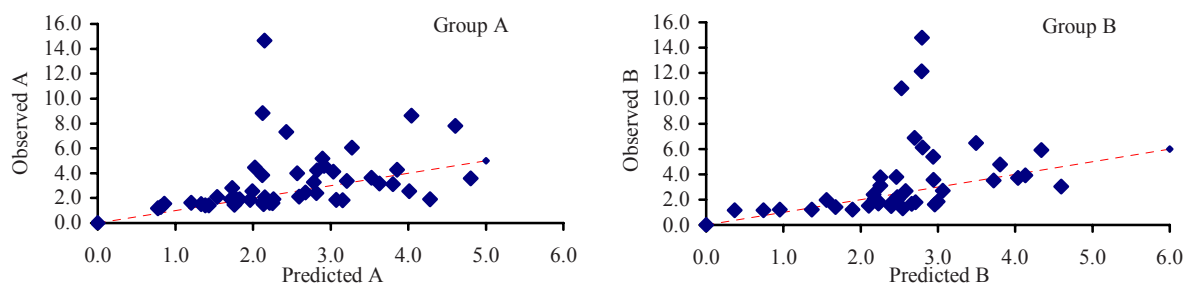


Fig. 2 Comparison of model predictions with observed priorities in stand groups A and B. Models fitted for consistent judges have been used. The dashed line represents a perfect match $v_{i(\text{obs})} = v_{i(\text{pred})}$.

Discussion

The models presented in this paper try to analyze the effect of different forest management alternatives on the people's scenic beauty perception. Variables included in the models as predictors are easily derived from normal inventories or predicted in simulations. Our models indicate that an enlargement in the mean diameter of trees increases the scenic beauty, which corresponds to previous studies (Arthur 1977; Brush 1979; Benson and Ullrich 1981; Buhyoff et al. 1986; Rudis et al. 1988). The presence of bushes represents in our study an increment in the perceived scenic beauty, which agrees with previous studies (Schroeder and Daniel 1981; Ribe 1990). Small trees on the contrary seem to have a negative effect on the perception of stand scenic beauty as previously reported by Brown and Daniel (1984) and Silvennoinen et al. (2001). The present study reflects increasing scenic beauty in denser stands, which disagrees with other studies (Silvennoinen et al. 2001). Another disagreement is with pine abundance, which has increased priorities in other studies (Brown 1987; Silvennoinen et al. 2001). However, this variation depends on what are those species that replace pine.

The preference of photographs over virtual reality images has also been mentioned by Bergen et al. (1995). However, a clear correlation was observed between the real photos and their virtual representations, meaning that when comparing photographs and virtual reality images of the same stands, those photographs of stands with a higher scenic beauty preference had also higher scenic beauty preference when evaluated for VRIs. From the existing correlation it can be concluded that the predictors affect in the same direction in photos and VRIs, but the priority level is higher for the photos. Due to this difference between photographs and VRIs we do not recommend mixing both types of visualization in the same regression analysis.

The differences in perception caused by the use of virtual reality images need further analysis. However, it has to be emphasized that there are clear advantages in the use of virtual reality images instead of real pictures. Virtual reality technology can represent all types of stands, even non-existing ones but reachable through new management practices. The use of virtual reality models allows also the selection of the same point of view for all the images and the exclusion of noise elements such as stones, paths, flowers, changes of light, etc.

Some limitations of our study that need to be considered in

future analyses are the use of a quite homogeneous population of judges, and the effect that a wide range of forest types and multiple predictive variables may have had on the modelling results. The study included a high percentage of judges receiving college education or being former university students. For this reason we asked the judges to forward the questionnaire to other people. College students are an interest group by themselves, and have shown to be representative of the total population (Daniel and Boster 1976). However, using a more carefully selected population would most probably improve the relevance of the study. Additionally, it was observed that by selecting the more consistent judges the models did not change significantly in terms of predictors' coefficients, but the models improved in terms of explained variance. Selecting a consistency threshold for the present study was based on visual analysis of the distribution of the judges' consistency and the number of remaining judges once the threshold was applied. The number of remaining judges should be large enough to provide a general view of the judges' opinion and at the same time those judges with internal consistencies clearly lower than the rest should be avoided.

The relatively low degree of explained variance in our models may have been caused by the use of several kinds of forest in the same analysis. Another reason is that people's scenic beauty preferences are purely subjective opinions, and grouping the judge population on the basis of their background did not remove the effects of between-judge differences. The use of virtual reality images allows the analyst to create images of stands in a flexible and interactive way, clearly different in terms of specific stand characteristics, making it possible to analyse the effect of each characteristic independently (stand structure, species composition etc.).

The present study shows the possibility of applying technologies like virtual reality models and internet questionnaires. These techniques make the data gathering process flexible, cheap and fast. Additionally, the modelling process using regression methods for pairwise comparisons offers a meaningful platform for analyzing continuous variables. Some of these variables are clearly relevant if the effect that different management options have on the scenic beauty at the stand level needs to be addressed.

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